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Solar PV System with Energy Storage System – An Engineer's View

14 July 2024

2nd Technical Seminar and General Membership Meeting

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PV System Overview

From Sunlight to Grid

Sunlight

PV Modules

DC / AC Inverter

Transformer

Substation

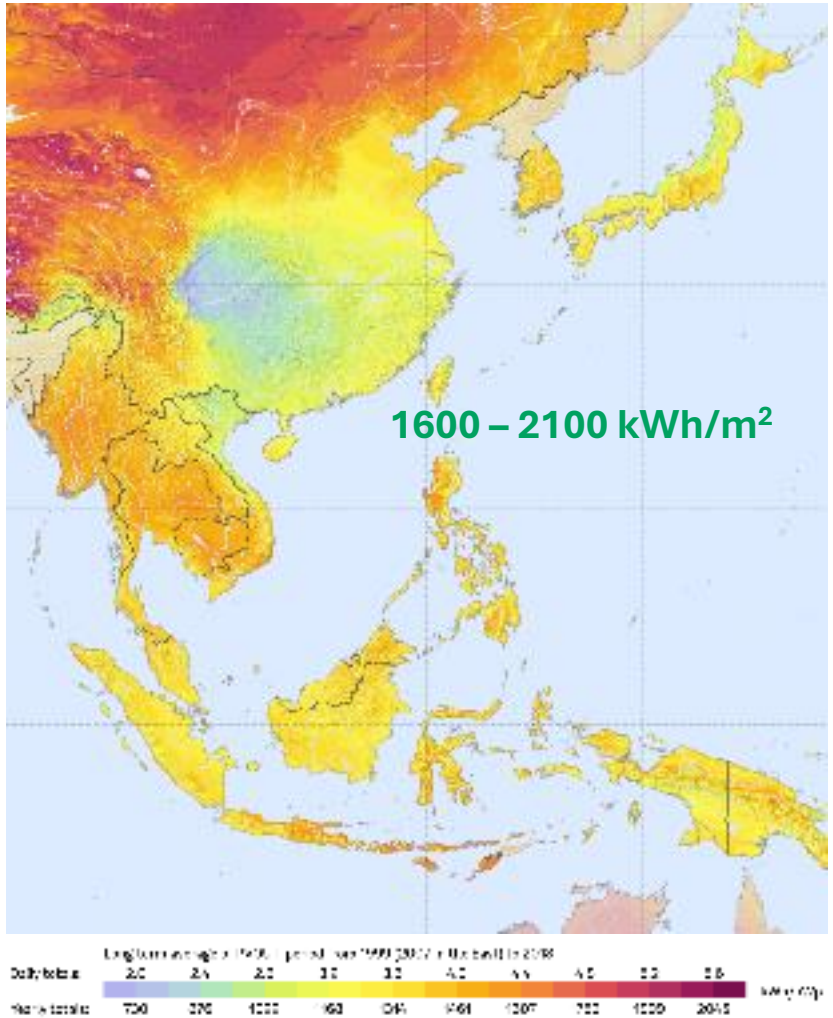
Transmission

Grid / Industry

Confidential

Sunlight and Solar PV Application

Sunlight

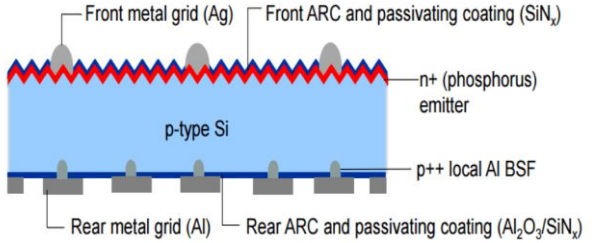


Application:

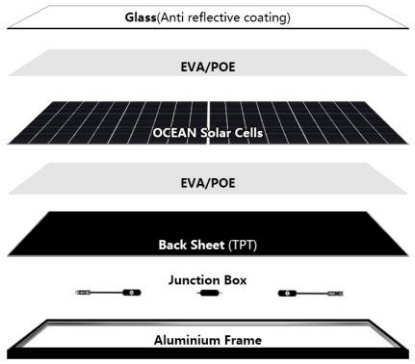
Confidential

PV Modules and Structures

PV Modules


Front metal grid (Ag)
Front ARC and passivating coating (SiN_x)
n+ (phosphorus) emitter
p-type Si
p++ local Al BSF
Rear metal grid (Al)
Rear ARC and passivating coating (Al_2O_3/SiN_x)

- Thin Film
- Polycrystalline
- Monocrystalline
- PERC
- **TOPCon**
- **HJT**
- IBC
- Perovskite



Structures

Fixed Structure

Rooftop

Tracker

Carport

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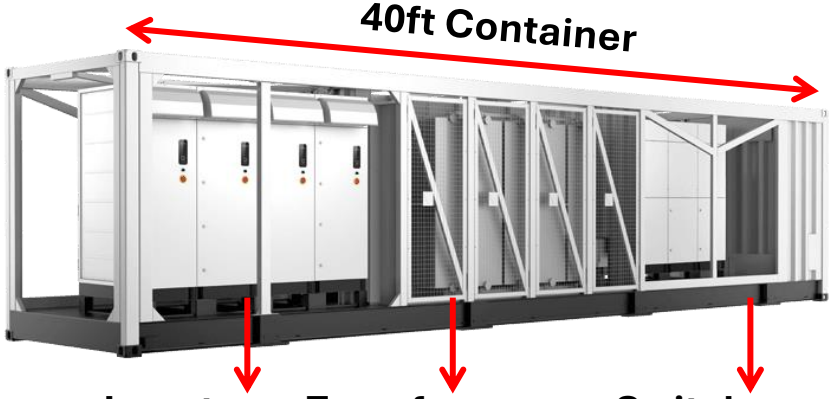
Large Scale Solar: DC and AC Collectors

DC/AC Inverter

Central Inverter

String Inverter

Power Conversion Station



Transformer

Large Scale Solar: HV Switching Stations

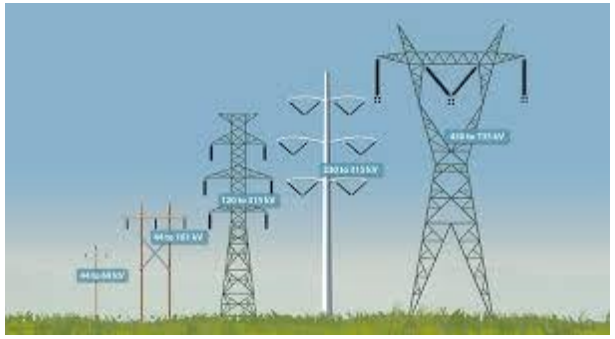
Substation

AIR INSULATED SWITCHGEAR

GAS INSULATED SWITCHGEAR

Large Scale Solar: Transmission and Development

Transmission to Grid



Other Technologies

Robot Cleaning

Drone Inspection

AI-driven Optimisation

Argi-voltaic

Confidential

Development Process

Overview on Development Process

Development Process	Residential	Commercial & Industrial	Utility Scale
Business Development	Resident Owner	Bidding/ Building Owner	Bidding/ Direct Negotiation with Utility + Land Owner
Feasibility Study			
• Financial Analysis	LCOE/ Payback Period	IRR/ LCOE	Project IRR/ Equity IRR
• Technical Analysis	0 – 100 kWp (Rooftop)	0 – 10 MWp (Rooftop/ Ground)	> 10 MWp (Ground/ Floating)
• Environment Impact Assessment	Not required	Not required (subject to local authority/ land status)	Required
Early Design and Engineering			
• Pre-development Test	Structural/ Pull Out Test	Structural/ Pull Out Test	Land Survey, Geotech, Hydro ..
• Solar Design Optimisation	Roof space and shading	Roof space, utilities on roof	Land boundary and waterway
• Structural Design	Penetration to Roof/ Clamp	Clamp/ Ballast/ Ground Mount	Ground Mount + Pitch
• Electrical Design	String Inverter (~25kW <1000V)	String Inverter (~100 kW <1500V)	String/ Central Inverter
• Others Compliances	Building and Fire Code	Building and Fire Code	Land Usage Requirement
Financing			
• Power Supply Agreement	Direct Purchase/ Leasing	Direct Purchase/ PPA	PSA
• Project Financing Method	Home Owner	Developer Equity	Developer Equity/ Bank Loan

Overview on Development Process

Development Process	Residential	Commercial & Industrial	Utility Scale
Permit and Approval			
• Grid Connection Agreement	Required beyond certain size	Required	+ System Impact Study
• Environmental Permits	Not required	Generally not required	Yes
• Government Incentives	Yes, typically sell back offset	Yes, typically sell back offset	Yes
• Procurement Clearances	Handled by local contractor	Yes	Yes
• Construction Permits	Yes (local government)	Yes (local government)	Yes (country level)
Mobilisation and Construction			
• Mobilisation and Construction	1-4 weeks	2-6 months	6 – 12 months or more
• Quality Assurance & Control	Contractor Checklist + Qualified Personnel	Qualified Personnel and Authority Representative	Owner's Engineer and Authority Representative
• Electrical Connection	1-phase, 240V	3-phases, 415V	>22kV on transmission line
• Final Acceptance Test	Standard checklist	Mainly Grid Safety Test	Capacity Test & Authority Witnessing
Operation and Maintenance			
• Monitoring	Inverter Logger	+Energy Meter and MET station	+ Power Plant Controller
• Maintenance Regime	Preventive and Corrective	Preventive and Corrective	Predictive, Preventive, and Corrective

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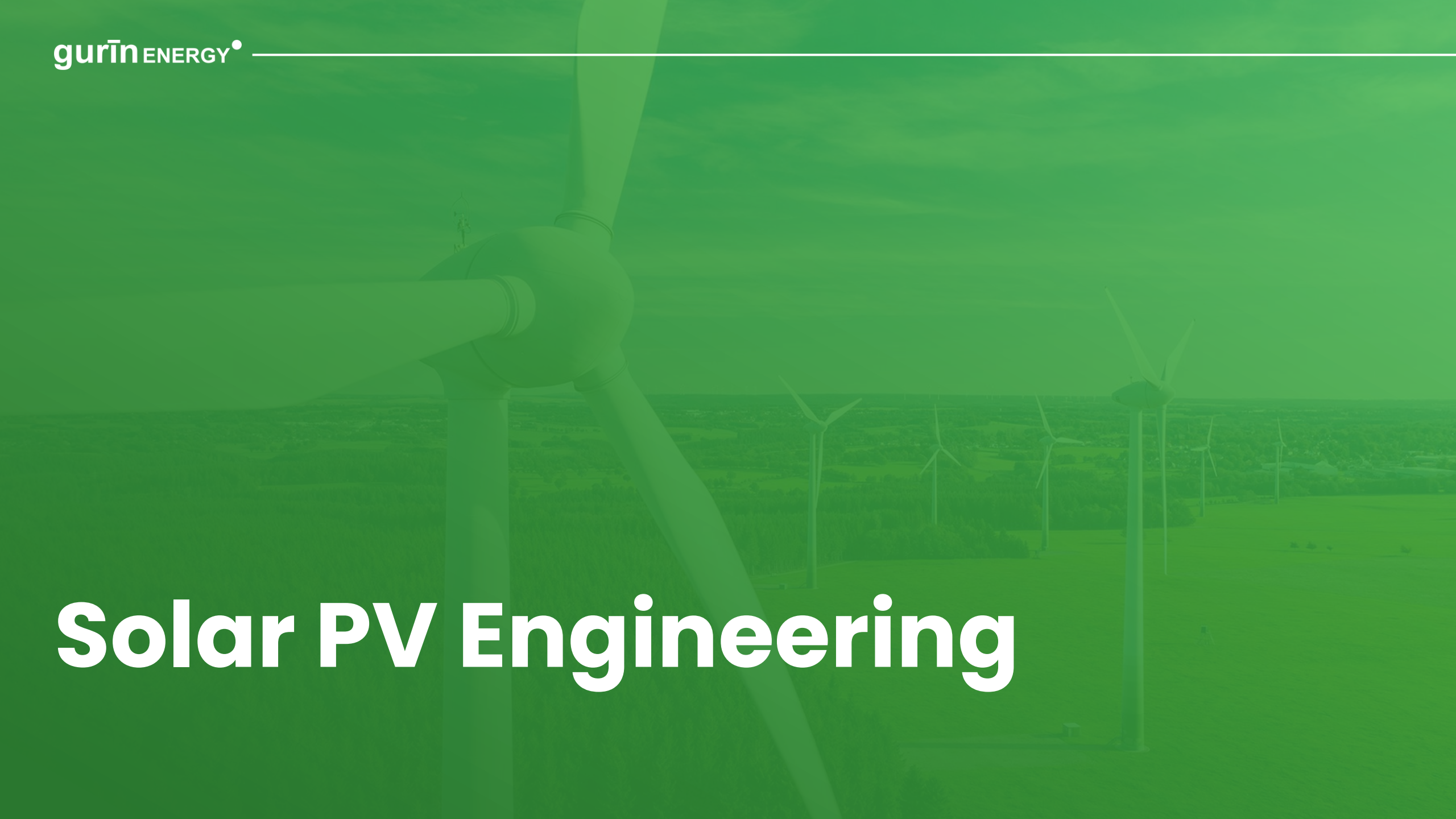
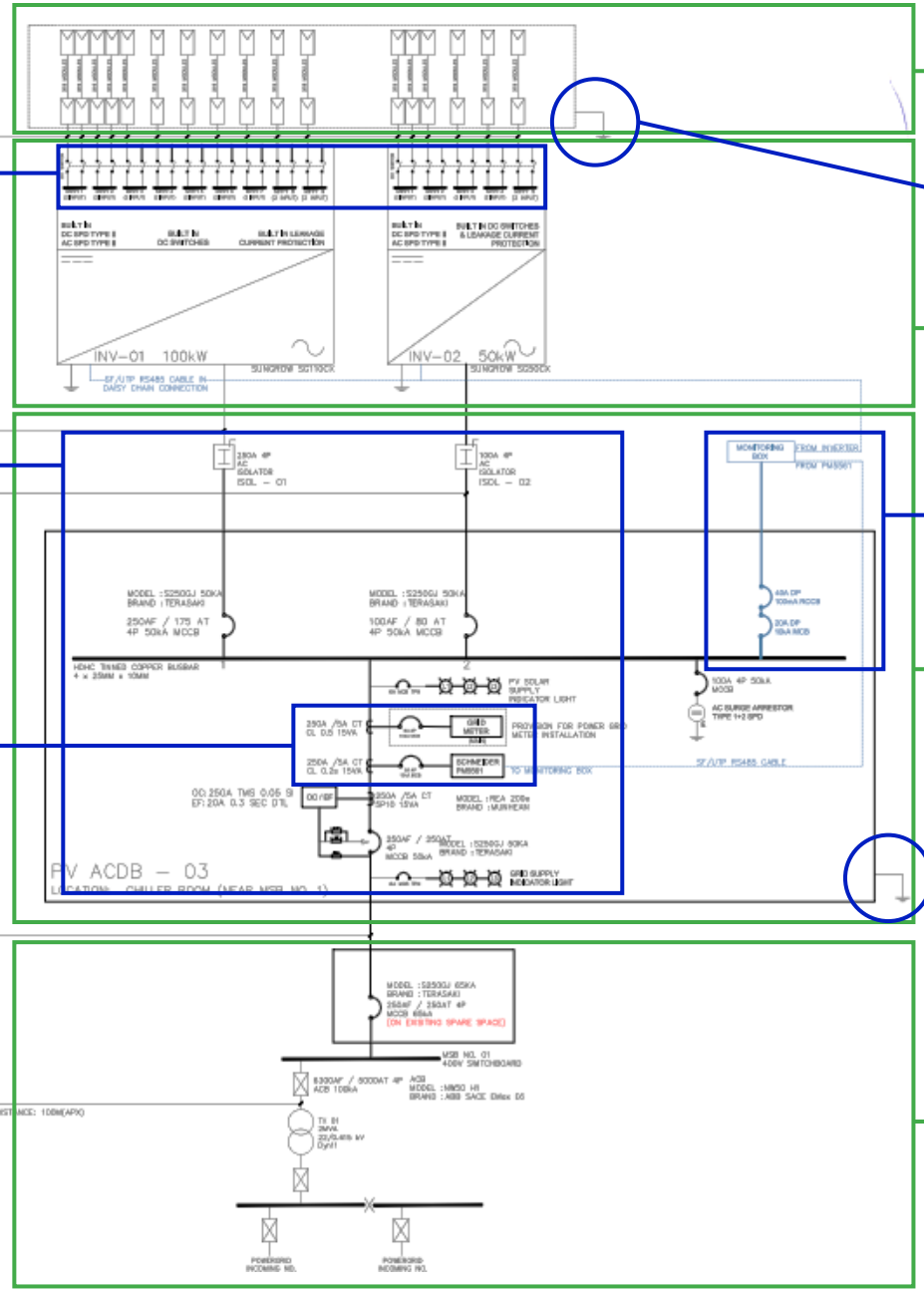


Solar PV Engineering

Typical Single Line Diagram


2 x 1C x 6 sq.mm H1Z2Z2-K SOLAR CABLE
INSIDE PERFORTATED CABLE TRUNKING
INV-01 100kW
INV-02 50kW
4 x 1C x 70 sq.mm Cu/XLPE/PVC
+ 1C x 35 sq.mm Cu/PVC CPC
INSIDE FLEXIBLE METAL CONDUIT
4 x 1C x 50 sq.mm Cu/XLPE/PVC
+ 1C x 25 sq.mm Cu/PVC CPC
PV ACDB – 03
4 x 1C x 95 sq.mm Cu/XLPE/PVC
+ 1 x 1C x 50 sq.mm Cu/PVC CPC
ON CABLE LADDER
CABLE DISTANCE: 30 METERS

DC Disconnector
(Fuse, SPD, DC switches)

AC Disconnector
(Isolator, Circuit Breaker,
OC/EF Relay, SPD)

Metering System

PV Strings & DC Collector System

Equipotential Bonding
and Earthing

Inverter

Monitoring System
& MET Station

AC Collector System

Building Earth

Grid Connection
(Transformer and Switchgear)

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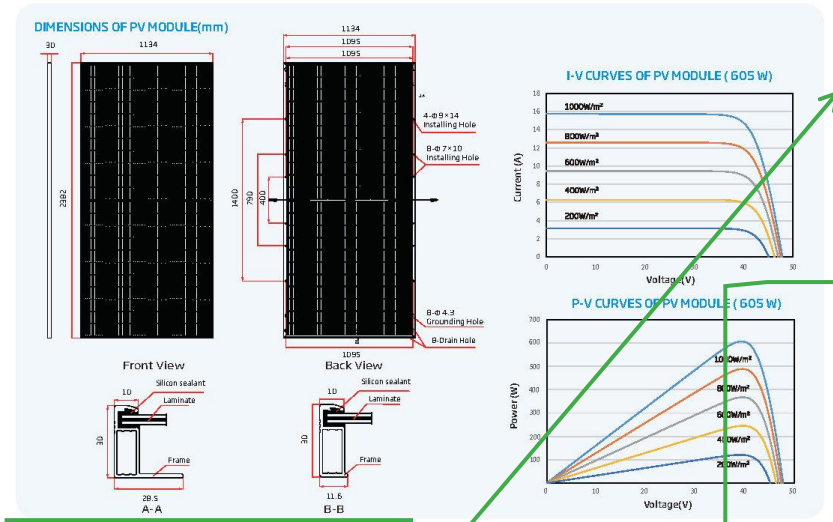
PV Modules Specification

Vertex N — N-type i-TOPCon bifacial dual glass Monocrystalline module



MECHANICAL DATA

Solar Cells	N-type Monocrystalline
No. of cells	132 cells
Module Dimensions	2382×1134×30 mm (93.78×44.65×1.18 inches)
Weight	33.7kg (74.3 lb)
Front Glass	2.0 mm (0.08 inches), High Transmission, AR Coated Heat Strengthened Glass
Encapsulant material	POE/EVA
Back Glass	2.0 mm (0.08 inches), Heat Strengthened Glass (White Grid Glass)
Frame	30mm(1.18 inches) Anodized Aluminium Alloy
J-Box	IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²) Portrait: 350/280 mm(13.78/11.02 inches) Length can be customized
Connector	MC4 EVO2 / TS4 PLUS / TS4*

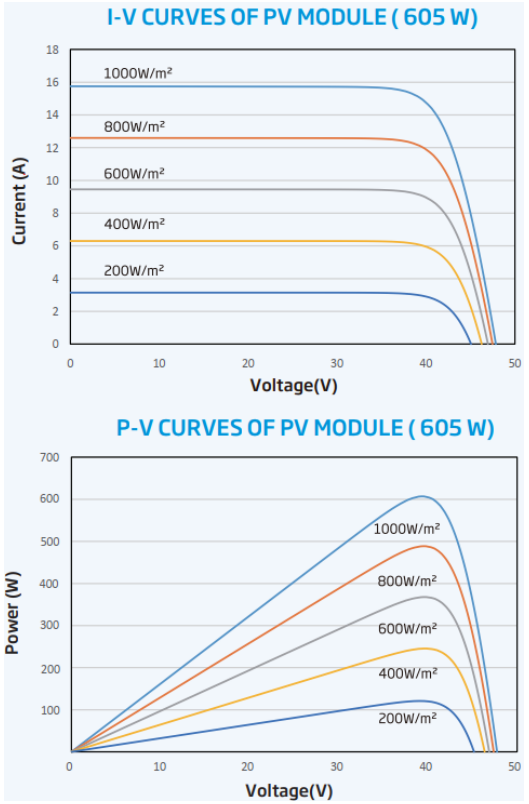
*Please refer to regional datasheet for specified connector.

STC: Irrdiance 1000W/m2, Cell Temperature 25°C, Air Mass AM1.5.

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

ELECTRICAL DATA (STC & NOCT

Testing Condition	STC	NOCT
Peak Power Watts-PMAX (Wp)*	605	462
Power Tolerance-PMAX (W)	0 ~ +5	
Maximum Power Voltage-VMPP (V)	40.5	38.1
Maximum Power Current-IMPP (A)	14.94	12.13
Open Circuit Voltage-Voc (V)	48.7	46.2
Short Circuit Current-Isc (A)	15.83	12.75
Module Efficiency η m (%)	22.4	



TEMPERATURE RATINGS

NOCT (Nominal Operating Cell Temperature)	43°C (±2°C)
Temperature Coefficient of PMAX	- 0.29%/°C
Temperature Coefficient of VOC	- 0.24%/°C
Temperature Coefficient of ISC	0.04%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85° C
Maximum System Voltage	1500V DC (IEC)
	1500V DC (UL)
Max Series Fuse Rating	35A

WARRANTY

12 year Product Workmanship Warranty

30 year Power Warranty

1% first year degradation

0.40% Annual Power Attenuation

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 36 pieces

Modules per 40' container: 720 pieces

Electrical characteristics with different power bin (reference to 5% & 10% backside power gain)

Backside Power Gain	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
Total Equivalent power -PMAX (Wp)	620	649	625	655	630	660	635	666	641	671	646	677	651	682
Maximum Power Voltage-VMPP (V)	39.7	39.7	40.0	40.0	40.3	40.3	40.5	40.5	40.8	40.8	41.1	41.1	41.4	41.4
Maximum Power Current-IMPP (A)	15.60	16.35	15.63	16.38	15.66	16.40	15.69	16.43	15.71	16.46	15.73	16.48	15.74	16.49
Open Circuit Voltage-Voc (V)	47.8	47.8	48.1	48.1	48.4	48.4	48.7	48.7	49.0	49.0	49.3	49.3	49.6	49.6
Short Circuit Current-Isc (A)	16.51	17.29	16.55	17.34	16.59	17.38	16.62	17.41	16.65	17.45	16.68	17.48	16.71	17.50

Power Bifaciality:80±5%.

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CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

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Version number: TSM_EN_2024_A

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PV Inverter Specification

Efficiency	
Max. Efficiency	≥99.0%
European Efficiency	≥98.8%
Input	
Max. Input Voltage	1,500 V
Number of MPP Trackers	6
Max. Current per MPPT	65 A
Max. Short Circuit Current per MPPT	115 A
Max. PV Inputs per MPPT	4/5/5/4/5/5
Start Voltage	550 V
MPPT Operating Voltage Range	500 V ~ 1,500 V
Nominal Input Voltage	1,080 V
Output	
Nominal AC Active Power	300,000 W
Max. AC Apparent Power	330,000 VA
Max. AC Active Power (cosφ=1)	330,000 W
Nominal Output Voltage	800 V, 3W + PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Nominal Output Current	216.6 A
Max. Output Current	238.2 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Total Harmonic Distortion	< 1%
Protection	
Smart String-Level Disconnector(SSLD)	Yes
Anti-islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Reverse-polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Type II
AC Surge Arrester	Type II
DC Insulation Resistance Detection	Yes
AC Grounding Fault Protection	Yes
Residual Current Monitoring Unit	Yes
Communication	
Display	LED Indicators, WLAN + APP
USB	Yes
MBUS	Yes
RS485	Yes
General	
Dimensions (W x H x D)	1,048 x 732 x 395 mm
Weight (with mounting plate)	≤108 kg
Operating Temperature Range	-25 °C ~ 60 °C
Cooling Method	Smart Air Cooling
Max. Operating Altitude without Derating	4,000 m (13,123 ft.)
Relative Humidity	0 ~ 100%
AC Connector	Waterproof Connector + OT/DT Terminal
Protection Degree	IP66
Topology	Transformerless

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Number of MPP Trackers	6
Max. Current per MPPT	65 A
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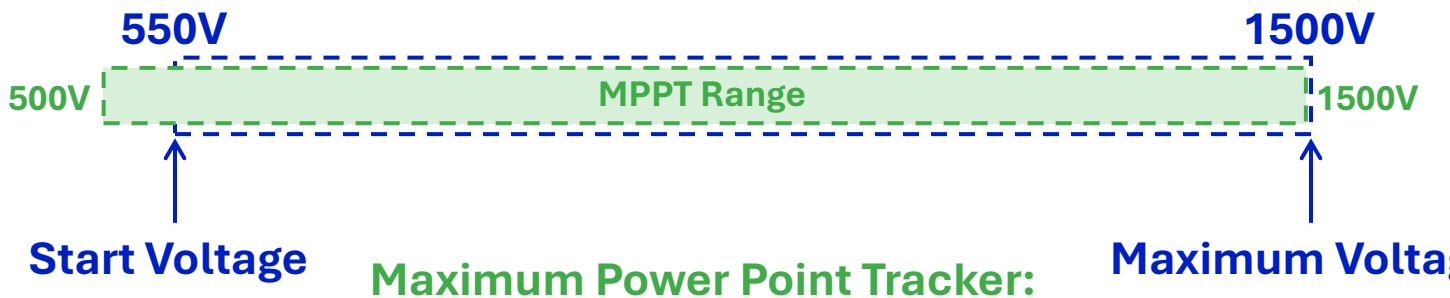
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Total Harmonic Distortion	< 1%

AC Circuit Breaker Size

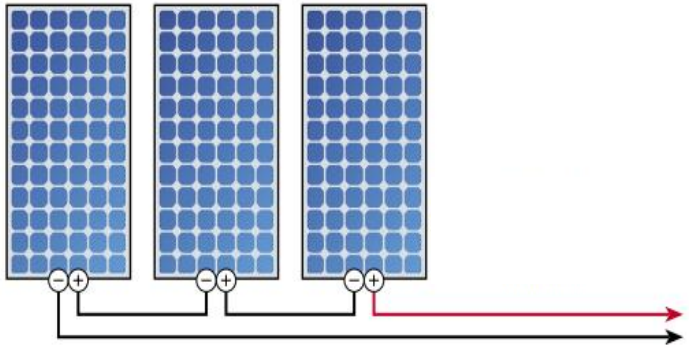


Maximum Power Point Tracker:

Control Algorithm to keep PV modules operating close to their peak power point (I x V)

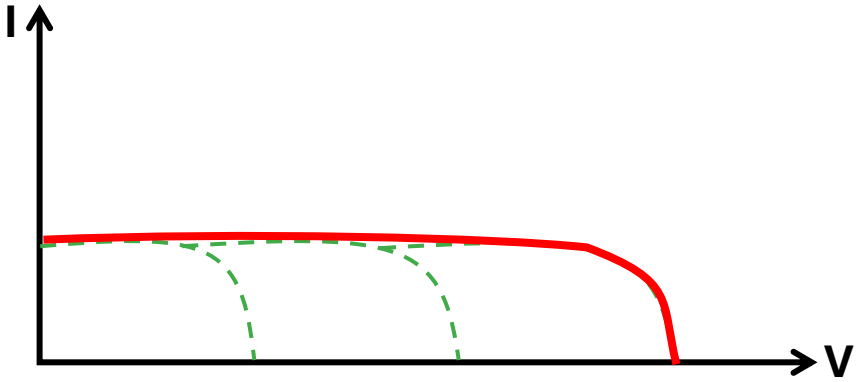
String and PV Array Configurations

PV String Arrangement

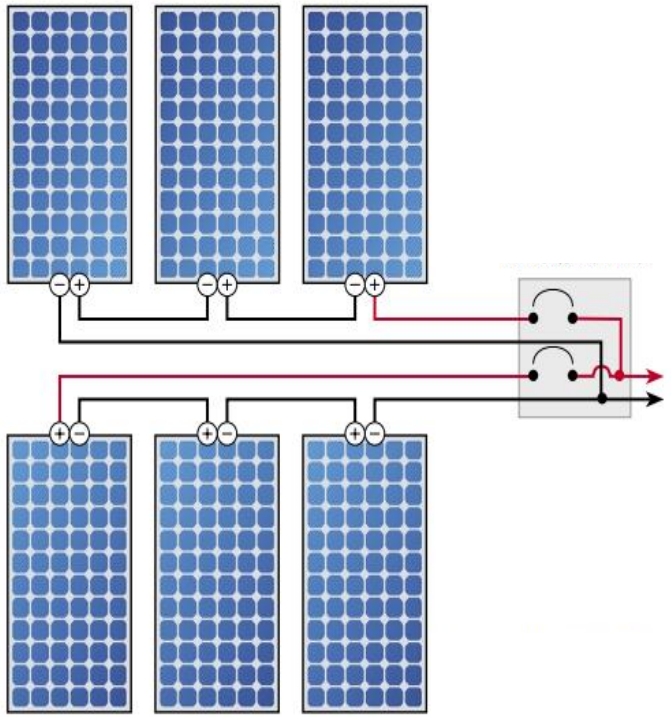


V_{oc} = 48.7 V / I_{sc} = 15.83A per PV modules

3 pcs PV modules in series (or string):
V_{oc_string} = 3 x 48.7 = **146.1 V**
I_{sc_string} = 1 x 15.83 = **15.83 A**



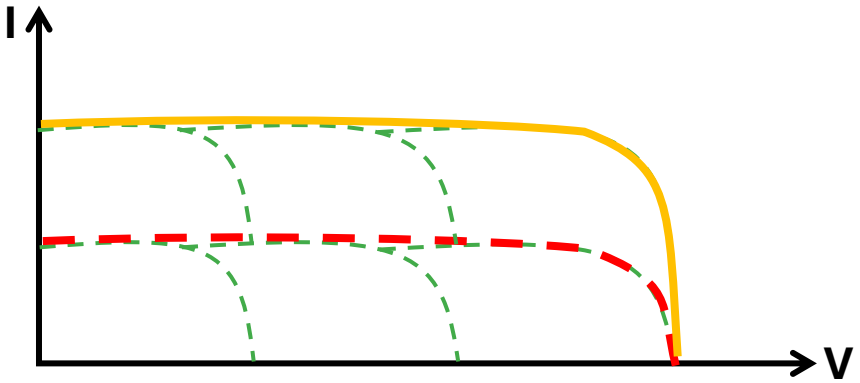
PV Array Arrangement



V_{oc} = 48.7 V / I_{sc} = 15.83A per PV modules

3 pcs PV modules in series (or string):
V_{oc_string} = 3 x 48.7 = 146.1 V
I_{sc_string} = 1 x 15.83 = 15.83 A

2 strings in an array:
V_{oc_array} = 1 x 146.1 = **146.1 V**
I_{sc_array} = 2 x 15.83 = **31.66 A**



AT STC (Standard Test Conditions)
Ambient Temperature: 25 °C
Irradiance: 1kWh/m²
Air Mass: 1.5

What happens onsite during operation?

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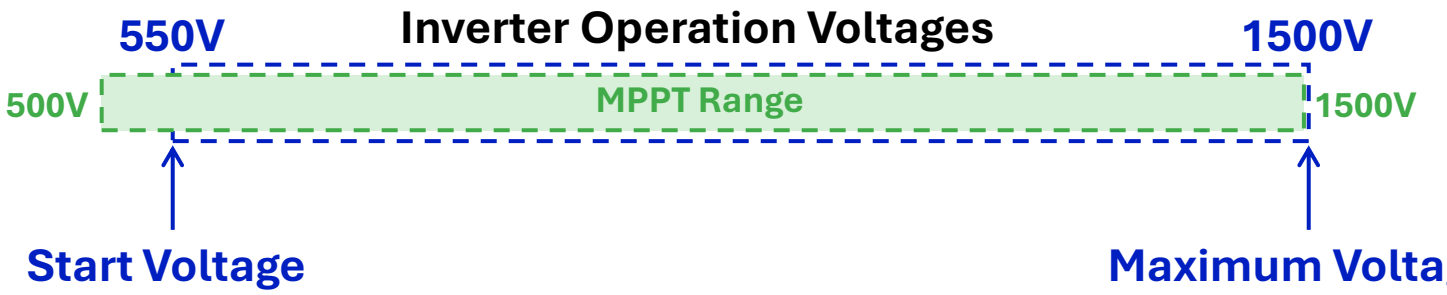
String and PV Array Configurations



$T_{cell}(°C) = T_{ambient}(°C) + [(NMOT(°C)-20) / 0.8] \times Irradiance\ (kW/m^2)$

$V_{oc,adjusted} = V_{oc,stc} + (Series\ PV\ Cells * k/q * T(K) * Diode\ Ideality\ Factor \times \ln(G/1000)) + \mu_{Voc} * (T_{cell}-T_{stc})$

energies

MDPI

Article

Adjusting the Single-Diode Model Parameters of a Photovoltaic Module with Irradiance and Temperature

Nader Anani [1,*] and Haider Ibrahim [2]

[1] School of Engineering, University of Wolverhampton, Telford TF2 9NT, UK
[2] Department of Electrical Technique, Southern Technical University, Technical Institute-Qurna, Basra, Iraq; haider.khalil@stu.edu.iq
* Correspondence: n.anani@wlv.ac.uk

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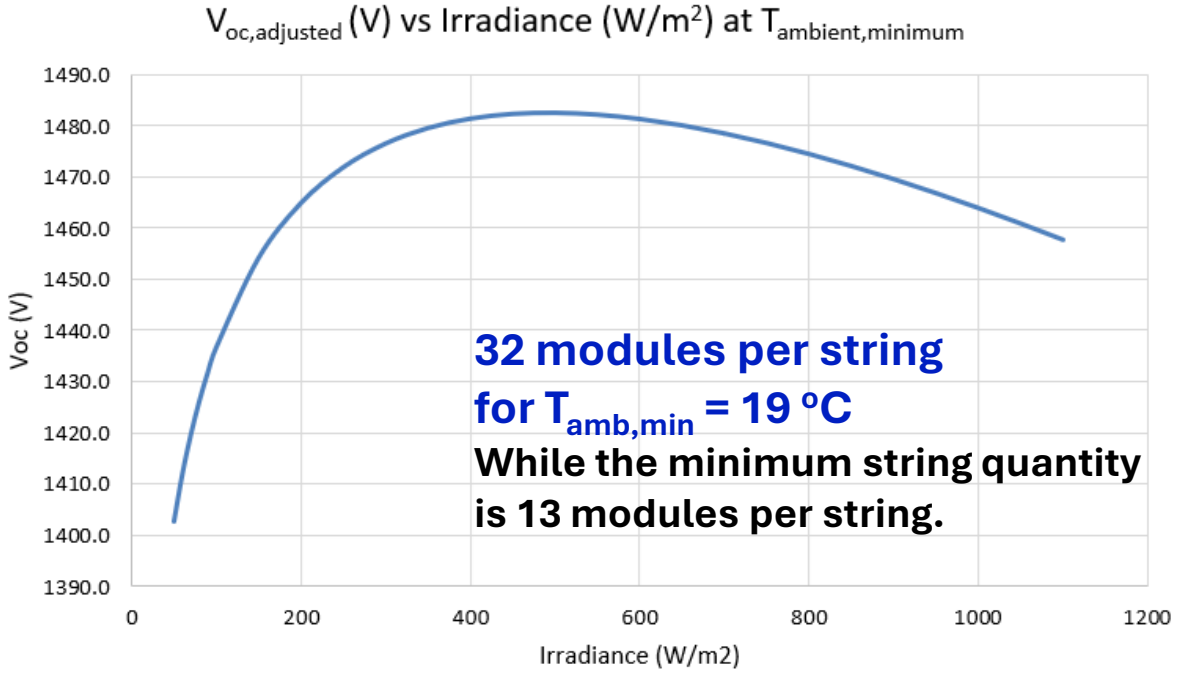

32 modules per string for $T_{amb,min}$ = 19 °C

While the minimum string quantity is 13 modules per string.

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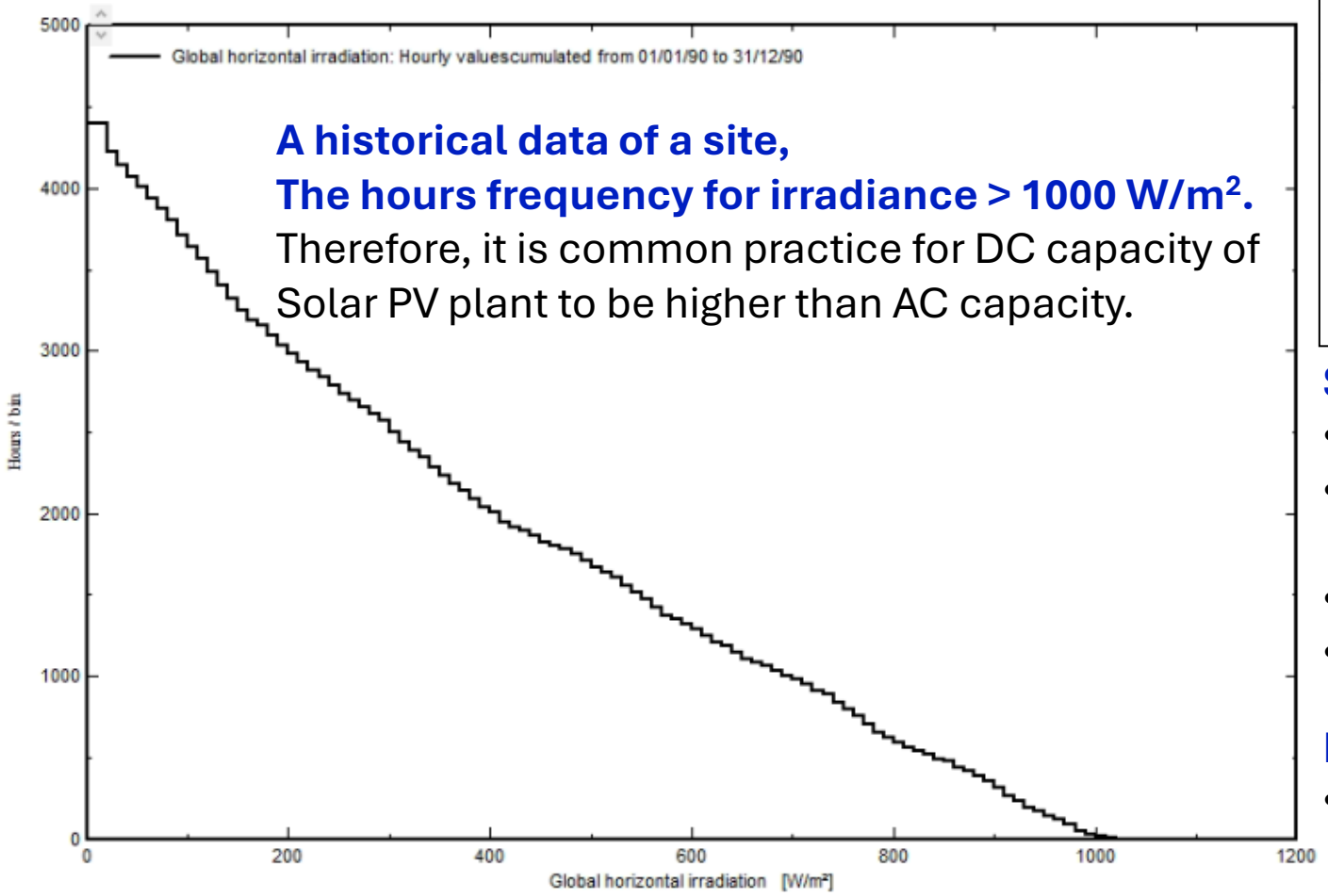
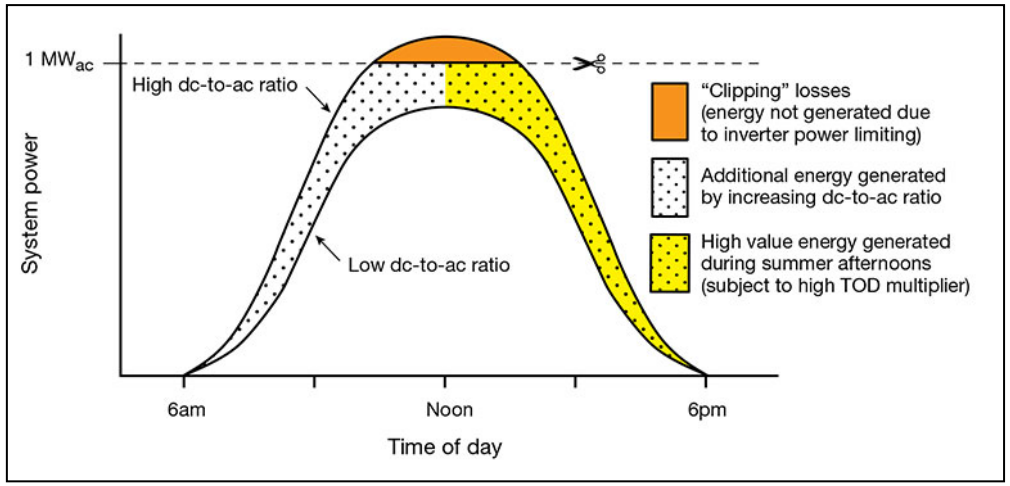
What's Good DC:AC Ratio?



A historical data of a site,
The hours frequency for irradiance > 1000 W/m².
Therefore, it is common practice for DC capacity of Solar PV plant to be higher than AC capacity.


1 MWac
High dc-to-ac ratio
Low dc-to-ac ratio
System power
6am
Noon
6pm
Time of day
"Clipping" losses (energy not generated due to inverter power limiting)
Additional energy generated by increasing dc-to-ac ratio
High value energy generated during summer afternoons (subject to high TOD multiplier)

Some Limiting Factors:

- Irradiance and temperature of the site
- Equipment operation limitation (i.e. temperature derating, number of DC inputs)
- Land availability
- Grid interconnection limitation

Rule of Thumb:

- 1.20 – 1.40 DC : AC ratio is generally acceptable for fixed tilt system in South East Asia

In our case:

- 100 kW Inverter → 120 – 140 kWp with 28 DC inputs available
- 1 strings = 32 modules x 605Wp = 19.36 kWp
- [120/ 19.36 = 6.2 strings] to [140/ 19.36 = 7.2 strings]

Select: 7 strings per inverter
7 x 19.36 kWp = 135.52 kWp / 100 kW
DC: AC ratio = 1.355 --> overloading loss to be simulated

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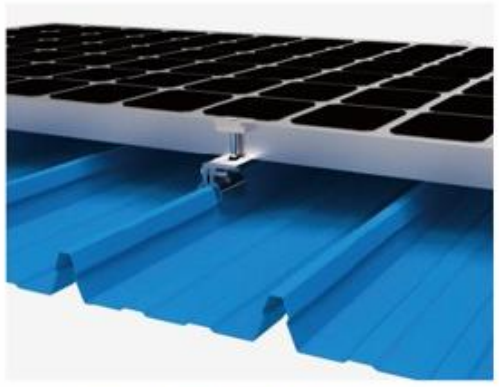
Structural Design

For Rooftop System:

Klip-Lok hook with end clamp

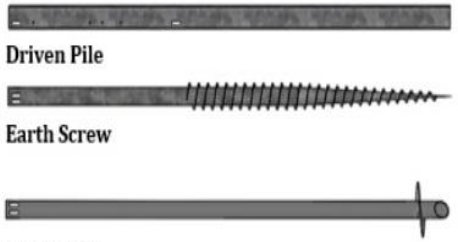


Klip-Lok hook with middle clamp

- Structural members verified by qualified engineers. (loading factor and deflection within specifications)
- Wind loading (uplift) calculation verified by qualified engineers supported with pull-out test on the clamping system.

For Ground Mount System:

Above, a typical PV support structure with penetrating foundations



Below, a typical PV support structure with ballasted founda

Ballasted

- Geotechnical study (STP N-value, soil type) and site topography
- Wind loading calculation verified by qualified engineer
- Onsite pull-out test

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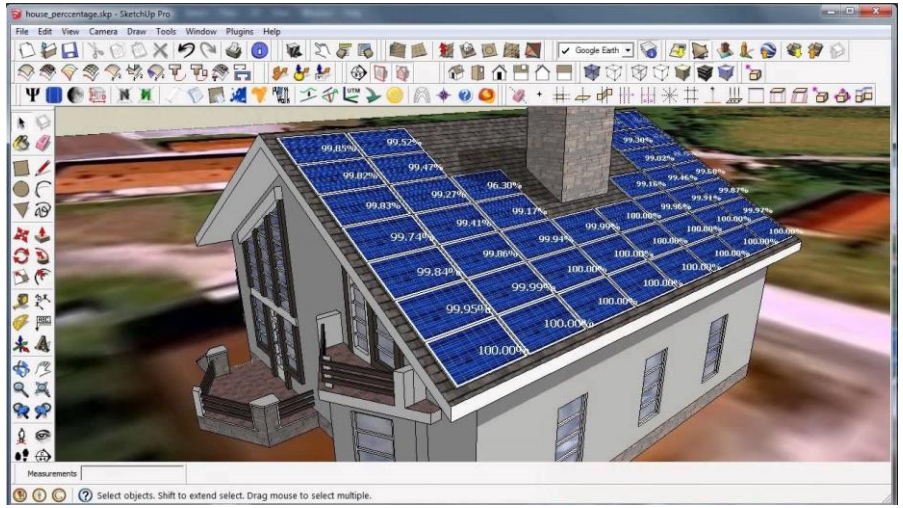
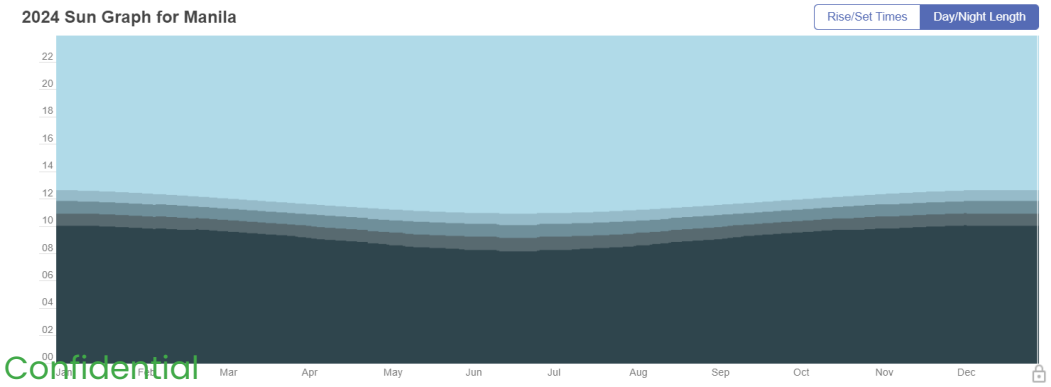
Shading on PV Modules

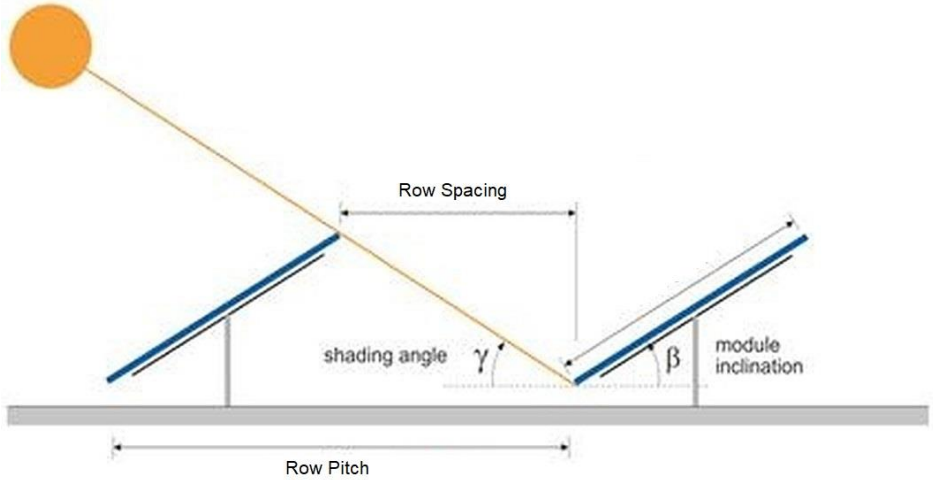
For Rooftop System:



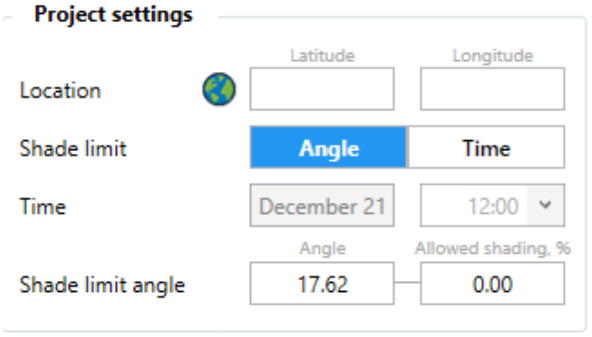
- Limited to roof pitch and existing structures
- This can be simulated with 3D models, which is typically done on SketchUp + Skelion Plug-in.
- Simulation test point is usually based on:
  Summer solstice (Jun 21th) --> longest daylight
  Winter solstice (Dec 21th) --> shortest daylight

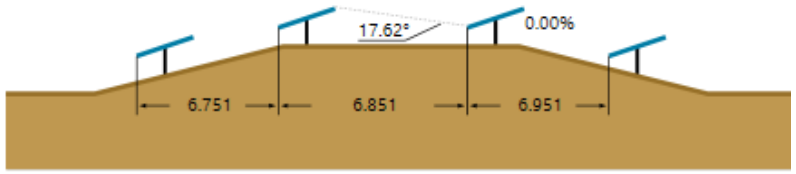


For Ground Mount System:



- Depending on the site terrain
- Affecting GCR (Ground Coverage Ratio) of the PV plant
- Defining maintenance space in between PV tables.





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Simulation Tools

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What is the KPI for Good PV System?

- Performance Ratio → ~80 – 83% performance ratio
- Technical Availability → ~ more than 99.0% availability
- Capacity Degradation → ~ less than 0.8% annual degradation

Temperature-corrected PR can be defined as follows:

$$PR_{TO}(i) = \frac{Y_i}{Y_{r\,(i)} \times \left[1 - \frac{\beta}{100} \times (T_{MOD(i)} - 25°C)\right]} \times 100$$

Where:

$PR_{TO}(i)$ = Temperature-corrected Performance Ratio for the period *i* (%)

$Y_f(i)$ = Plant Specific Yield for the period *i*, expressed in (kWh/kW$_p$) or peak sun hours (h)

$Y_r(i)$ = Reference Yield for the period *i*, expressed in (kWh/kW$_p$) or peak sun hours (h)

β = Temperature coefficient of the installed modules (%/°C)

P_0 = Plant Peak DC power (nominal power) (kW$_p$)

$T_{MOD}(i)$ = Average module temperature for the period *i*, weighted according to Specific Yield $Y_f(j)$ (°C) - *see formula below.*

$$T_{MOD}(i) = \frac{\sum_{j=1}^{i} Y_{f\,(j)} \times T_{MOD_{MEAS(j)}}}{\sum_{j=1}^{i} (Y_{f\,(j)})}$$

$T_{MOD}(i)$ = See above

$Y_f(j)$ = Plant Specific Yield for the period *j*, expressed in (kWh/kW$_p$) or peak sun hours (h)

$T_{MOD}(j)$ = Module temperature for the period *j* (°C)

Contractual Availability is therefore defined and calculated as:

$$A_c = \frac{T_{useful} - T_{down} + T_{excluded}}{T_{useful}} \times 100$$

Where:

A_c = Contractual Availability (%)

T_{useful} = Period of time with in-plane irradiation above MIT (h)

T_{down} = Period of T_{useful} when the system is down (no production) (h)

$T_{excluded}$ = Part of T_{down} to be excluded because of presence of an exclusion factor (see below) (h)

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Storage Integration

Services Energy Storage System Can Provide

ELECTRIC SUPPLY	ANCILLARY SERVICES	GRID SYSTEM	RENEWABLE INTEGRATION	END USER/ UTILITY CONSUMER
Electric Energy Time Shift	Load Following	Transmission Support	Renewable Energy Time-shift	Time-of-use Energy Cost Management
Electric Supply Capacity	Area Regulation	Transmission Congestion Relief	Renewable Capacity Firming	Demand Charge Management
	Electric Supply Reserve Capacity	Transmission & Distribution Relief	Wind Generation Grid Integration	Electric Service Reliability
	Voltage Support	Substation On-site Power		Electric Service Power Quality

Source: Othman Hisham, Energy Storage Applications in Transmission and Distribution Grids (2022)

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Services to Grid

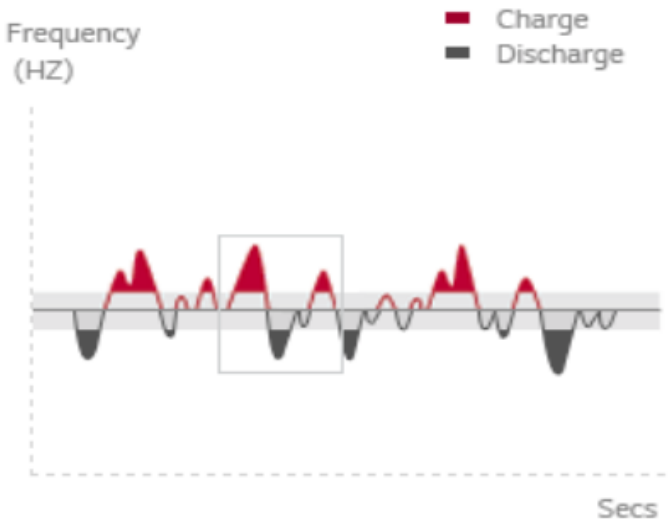
Ancillary Services

- Frequency Response/ Regulations
- Voltage Support
- Capacity Reserve
- Black Start

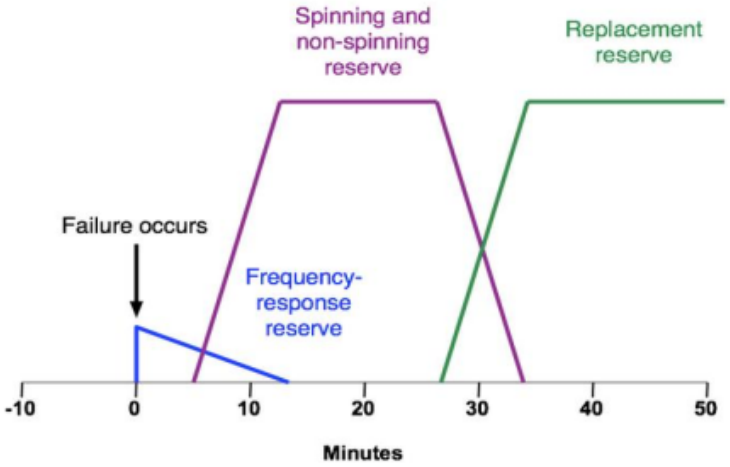
Improving Grid Reliability

- Network Congestion Relief
- Transmission and Distribution Infrastructure Investment Deferral

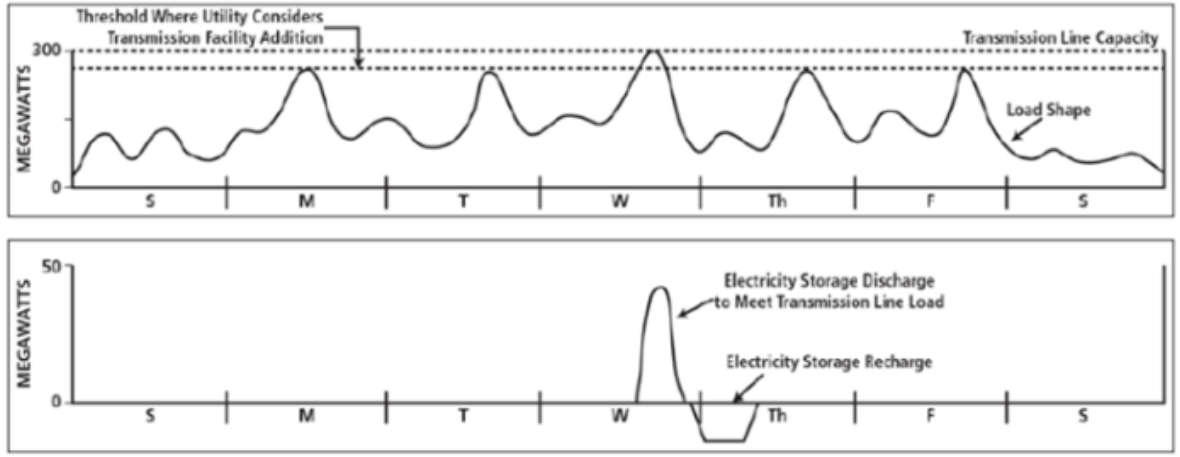
Frequency Regulation



Reserve Capacity



Congestion Relief



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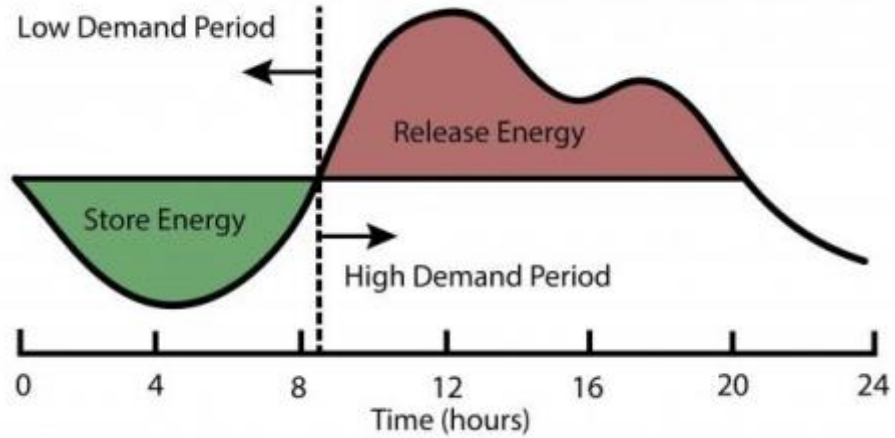
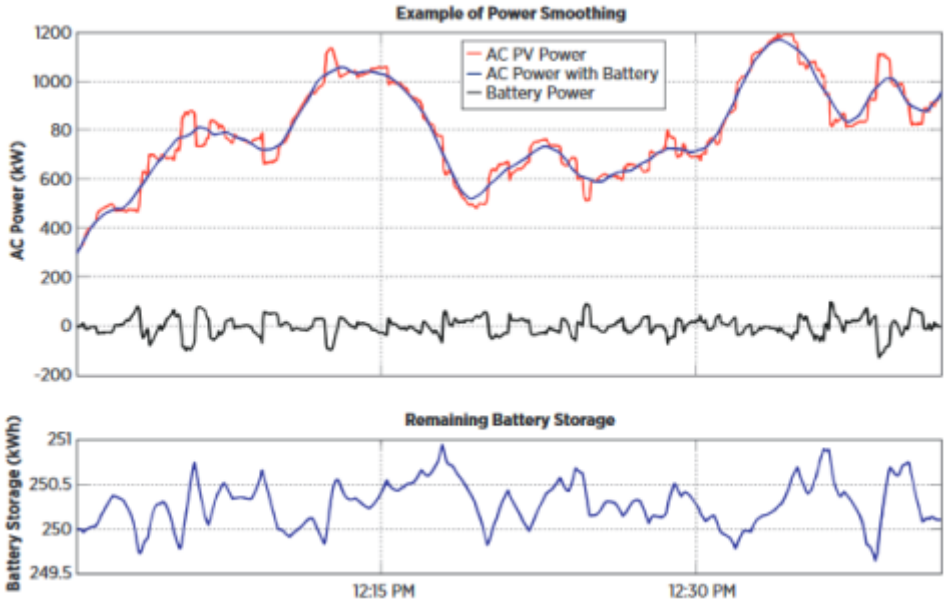
Utility Services

- **Energy Shifting**
  (arbitrage, capacity firming, defined generation profile, reduce imbalance from scheduled generation)
- **Capacity Market**
- **Renewable Energy Integration**
  Power Smoothing/Ramp Rate Control
  Limit Curtailment/Avoid Clipping (for PV)
- **Optimisation of Conventional Generation**

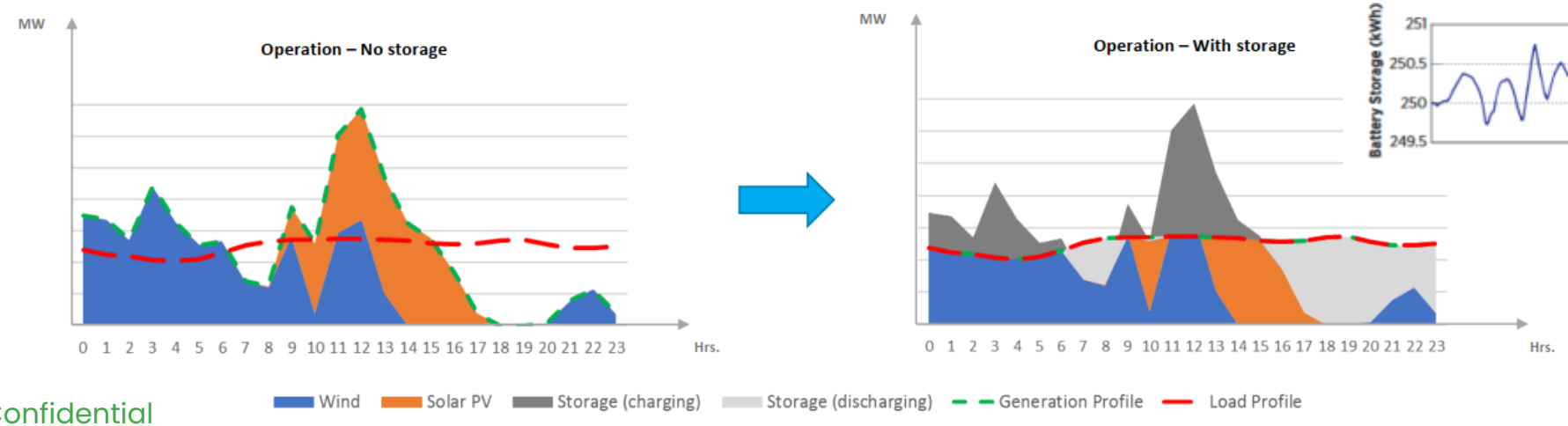
Energy Arbitrage



Power Smoothing



Renewable Integration


MW
Operation – No storage
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hrs.
MW
Operation – With storage
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hrs.
Wind
Solar PV
Storage (charging)
Storage (discharging)
Generation Profile
Load Profile

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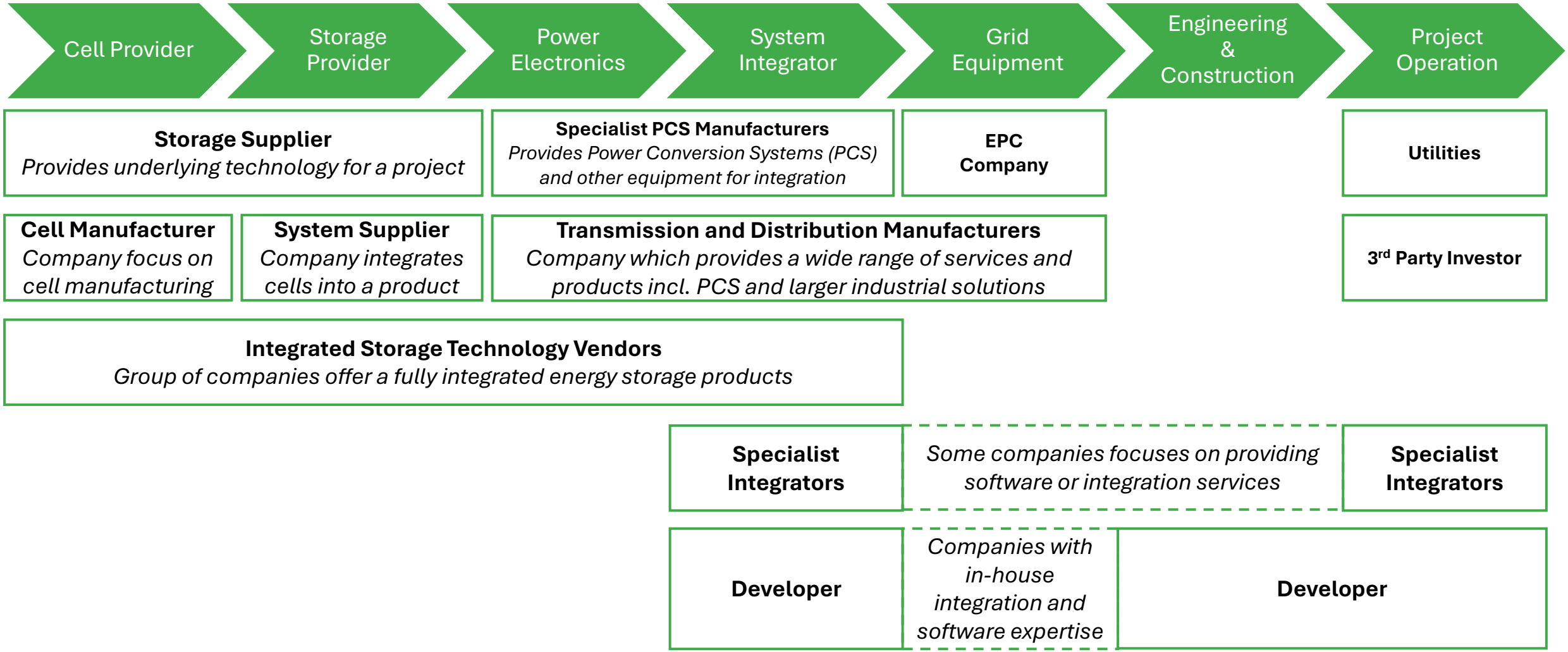
ESS Market Structures


Cell Provider
Storage Provider
Power Electronics
System Integrator
Grid Equipment
Engineering & Construction
Project Operation
Storage Supplier
Provides underlying technology for a project
Specialist PCS Manufacturers
Provides Power Conversion Systems (PCS) and other equipment for integration
EPC Company
Utilities
Cell Manufacturer
Company focus on cell manufacturing
System Supplier
Company integrates cells into a product
Transmission and Distribution Manufacturers
Company which provides a wide range of services and products incl. PCS and larger industrial solutions
3rd Party Investor
Integrated Storage Technology Vendors
Group of companies offer a fully integrated energy storage products
Specialist Integrators
Some companies focuses on providing software or integration services
Specialist Integrators
Developer
Companies with in-house integration and software expertise
Developer

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Energy Storage Technologies

Electrical Energy Storage Systems

Electrical	Mechanical	Thermal	Chemical
• Super Capacitor • Superconductive Magnetic Coil	• Flywheels • Pumped Hydro Power • Compressed Air Energy Storage System	• Thermoelectric Storages	• Lithium Ion Battery • Lead Acid Battery • High Temperature Batteries • Flow Batteries • Hydrogen Storage • Natural Gas Storage System

In this Discussion

Storage Time Scale

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Main Battery Technologies in Use

Battery Technology		Sodium-Sulphur	Conventional Lead-Acid	Lithium-ion[1]	Flow Batteries
Power Component Cost	$/kW	300 – 500	300 – 500	300 – 350	600 – 900
Energy Component Cost	$/kWh	200 – 400	150 – 250	180 – 230	150 – 180
Cycle Life	nr.	4,000 – 5,000	500 – 1,000	2,000 – 7,000	7,000 – 20,000
Calendar Life	Years	15 – 20	15 – 20	10 – 20	10 – 20
Roundtrip Efficiency (DC)[2]	%	75 – 85	60 - 80	90 – 99	60 – 80
Energy Density	Wh/kg	150 – 220	40 - 60	80 – 260	15 – 70
	Advantages	• *Long and proven operational history - Japan* • *High energy density* • *Good cycle & calendar life expectancy*	• *Long and proven operational history* • *Ongoing R&D into "advanced" lead-acid batteries*	• *High energy density* • *High roundtrip efficiency* • *Strong continued R&D*	• *Attractive for long-duration applications (low $/kWh)* • *Good cycle & calendar life expectancy*
	Drawbacks	• *Safety concerns: high operating temperature* • *Costs have not declined significantly in recent years* • *Limited suppliers*	• *Low cycle life* • *Low Energy Density* • *Flammability concerns* • *Environmental concerns*	• *Safety is a concern (thermal runaway)* • *Some chemistries rely on relatively rare elements, which could lead to price spikes*	• *Little operating experience* • *Low Energy Density* • *Lower roundtrip efficiency* • *Environmental concerns (spillage present toxicity risk)*

[1]Excludes Lithium Titanate (LTO) chemistry that has a longer life-cycle, but also a higher energy cost when compared to other lithium chemistries.

[2]AC efficiency will depend on conversion equipment, use case and ambient/local conditions

Source: Bloomberg –New Energy Finance, IHS Global Insight (2019)

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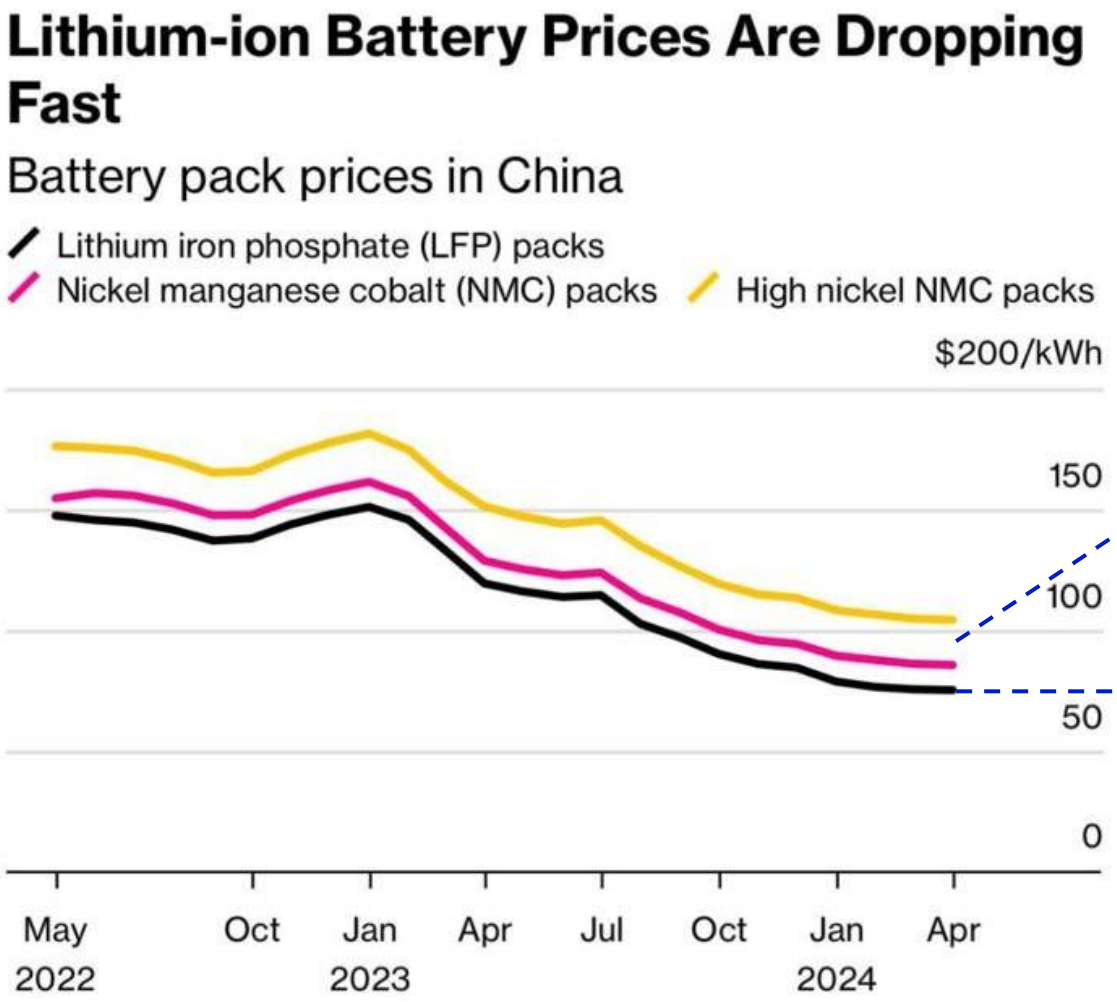
Lithium-Ion Battery



Source: BloombergNEF, ICC Battery
Note: NMC = Nickel manganese cobalt and includes prices for NMC111, NMC532 and NMC 622 batteries. High-nickel NMC includes NMC811, NMC955 and NCA

NMC for EVs and Consumer Electronics

$53/kWh (Apr 2024) LFP popular for stationary ESS

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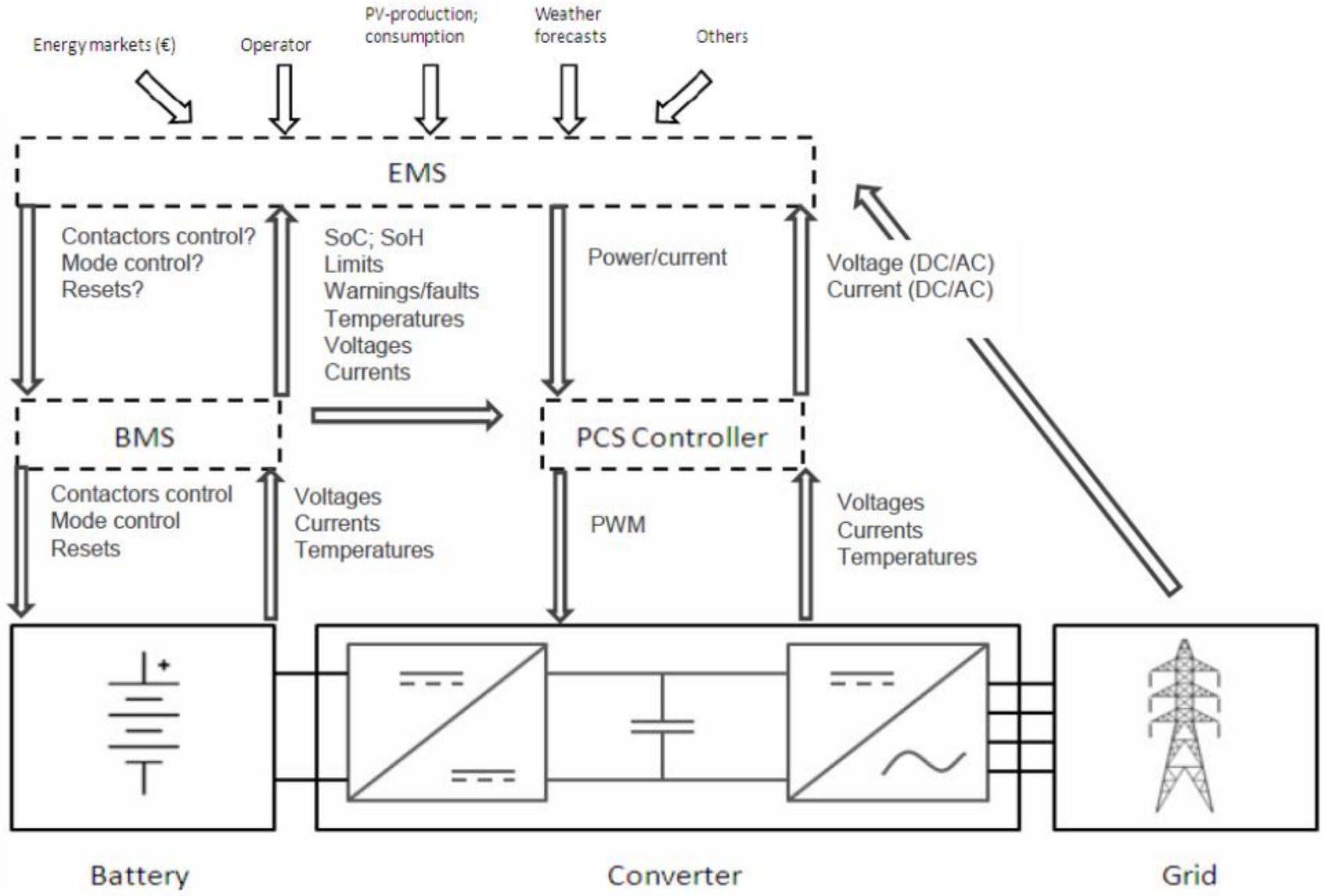
Battery Energy Storage System Overview

Main Components:

- Battery Packs (MWh)
  + Battery Management System
- Power Conversion System (MW)
  + Converter with Controller
- Energy Management System (EMS)
- Heating, Ventilation, and Air Conditioning (HVAC)
- Fire Detection and Suppression System
- Interconnection Equipment



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Battery Energy Storage System Overview

Battery DC Block

Battery Cell

Battery Modules

Container

Component	Cell	Modules	Container
Configuration	Single cell	1P52S	10P416S
Dimension (mm)	174 x 207 x 73	740 x 1050 x 230	2464 x 6058 x 2896
Weight (kg)	5 kg	330 kg	35,000 kg
Rated Voltage (V)	3.2	166.4	1331.2
Rated Current (A)	2.8 ~ 3.6	145.6 ~ 187.2	1164.8 ~ 1497.2
Rated Energy (kWh)	0.896	46.59	3727.36

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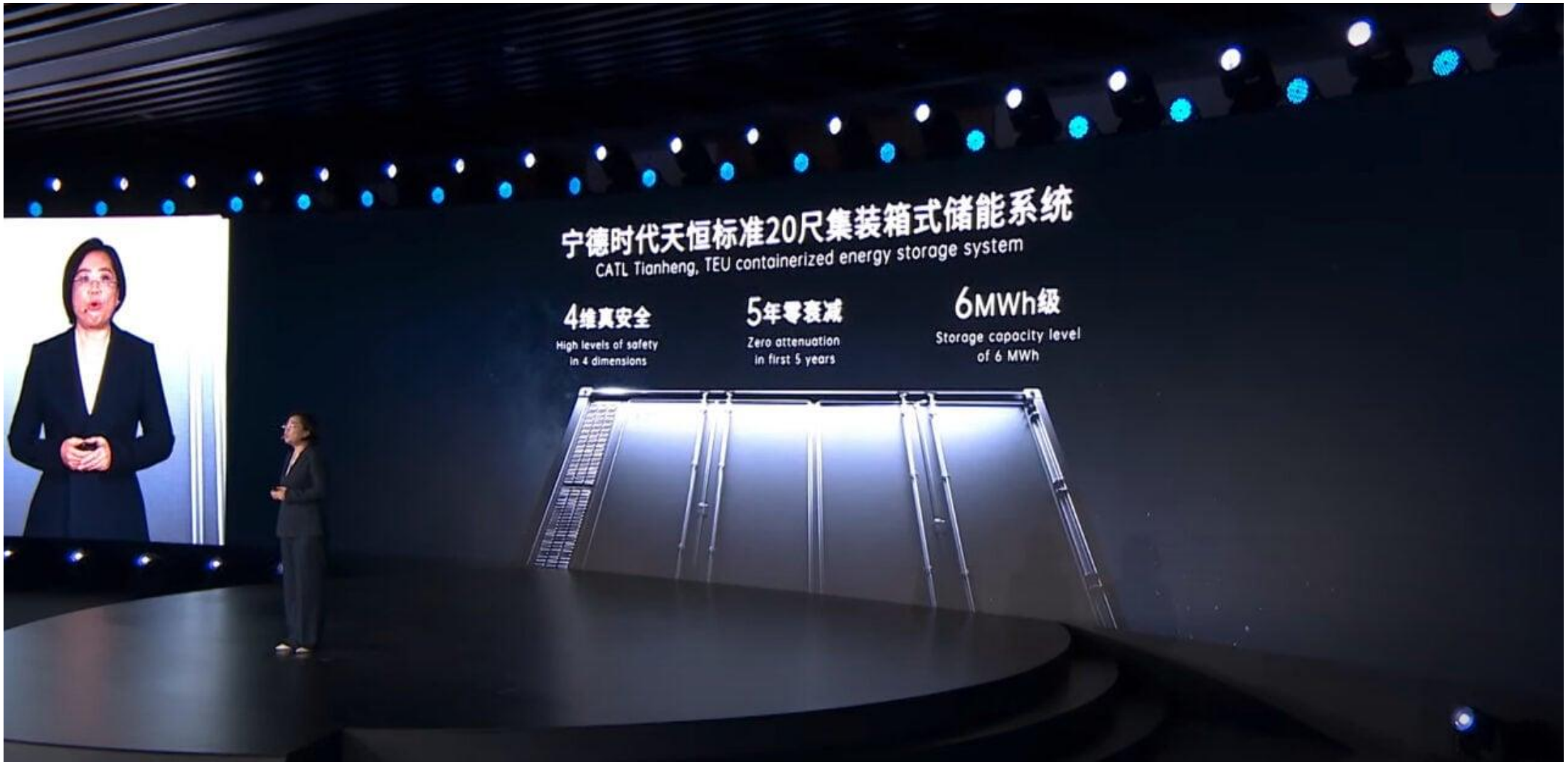
Battery Energy Storage System Overview



New grid-scale battery energy storage system (BESS) DC block product, Tener, which has 6.25MWh of energy per 20-foot container. (Energy Storage News, April 2024)

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Main Battery Terminology

- **State of Charge (SoC)**
  Amount of energy still remain in the system as percentage of usable storage capacity.

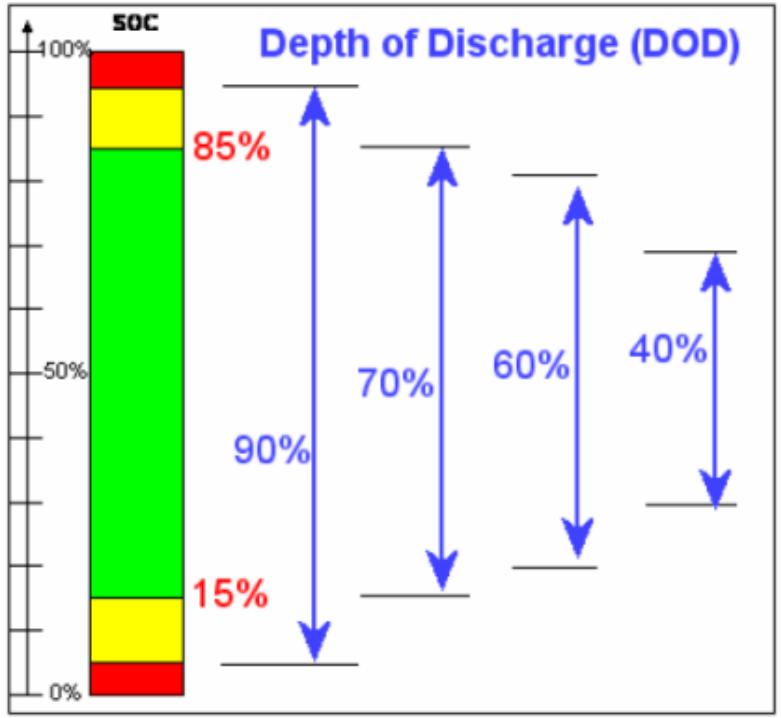
- **Depth of Discharge (DOD)**
  Percentage of energy taken from the battery.

- **End of Life (EOL)**
  Remaining capacity is typically 60% - 70% of the initial capacity.

- **State of Health (SOH)**
  Present capacity compared to initial capacity (100%)
  SOH at EOL = 0% (e.g. 60% remaining capacity)

- **C-rate**
  Expression of (dis)charge current of a battery in order to normalise against battery capacity.
  1C means discharge full capacity in 1 hour
  0.5C means discharge full capacity in 2 hours

$$SoC = \frac{Present\ stored\ capacity}{Present\ full\ capacity}$$



$$SoH = \frac{Present\ capacity - EOL\ capacity}{Initial\ capacity - EOL\ capacity}$$

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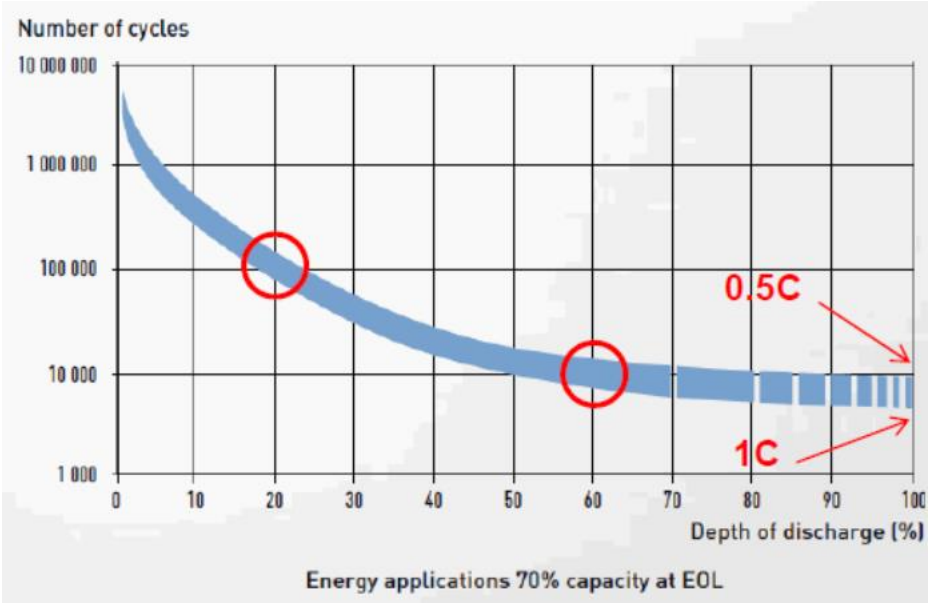
Main Battery Terminology

- **Cycle Life**
  Number of charge/ discharge cycles (full equivalent cycles) that can be achieved until EOL.
  High DOD -> less cycles, i.e. 20% DOD leads to 100,000 cycles, 60% DOD leads to 10,000 cycles.
  High C-rate -> less cycles, i.e. 1C 100% DOD leads to 4,000 cycles, 0.5C 100% DOD leads to 9,000 cycles.



Energy applications 70% capacity at EOL

- **Calendar Life**
  Expected battery lifetime in years without cycling.
  Higher temperature -> higher aging and
  too low temperature -> higher aging.
  i.e. Lead-acid battery aging doubles for every 10°C increase in temperature

  Leaving Li-Ion battery on high SoC level for long time leads to higher aging
  Leaving Lead-acid battery on low SoC level for long time leads to higher aging.

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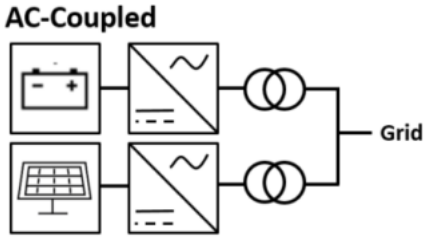
BESS Integrations with Solar PV System

Three main configurations to couple BESS and PV System:

- **AC-coupled system**

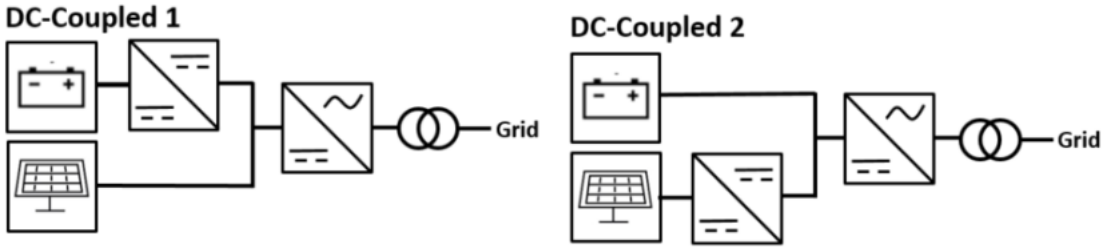


AC-coupled is commonly found in the utility scale projects.

It allows BESS to be centralized close to AC interconnection point and flexibility in design ratio.

One main disadvantage is conversion inefficiency from DC – AC – DC and AC again.

- **DC-coupled system**

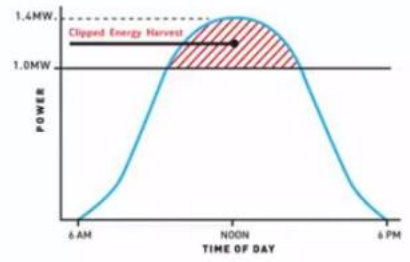


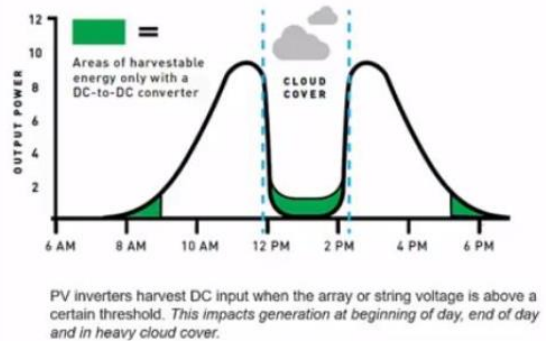
DC-Coupled 1 is most commonly used for DC-coupled PV+ Battery configuration

BESS coupled to PV array through a DC/DC converter before a PV Inverter

Advantages:

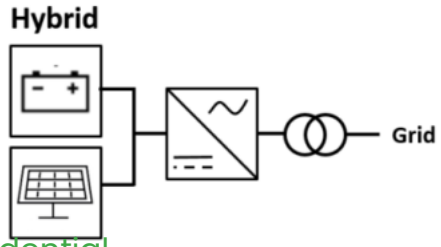
- *Lower CAPEX (sharing inverter, transformer and switchgear)*
- *Clipping recapture before PV inverter*
- *Simplified system impact study (only PV inverter)*
- *Low voltage harvest*





PV inverters harvest DC input when the array or string voltage is above a certain threshold. *This impacts generation at beginning of day, end of day and in heavy cloud cover.*

- **Hybrid – a common hybrid inverter**
  (PV and BESS connected through a DC/DC Converter)



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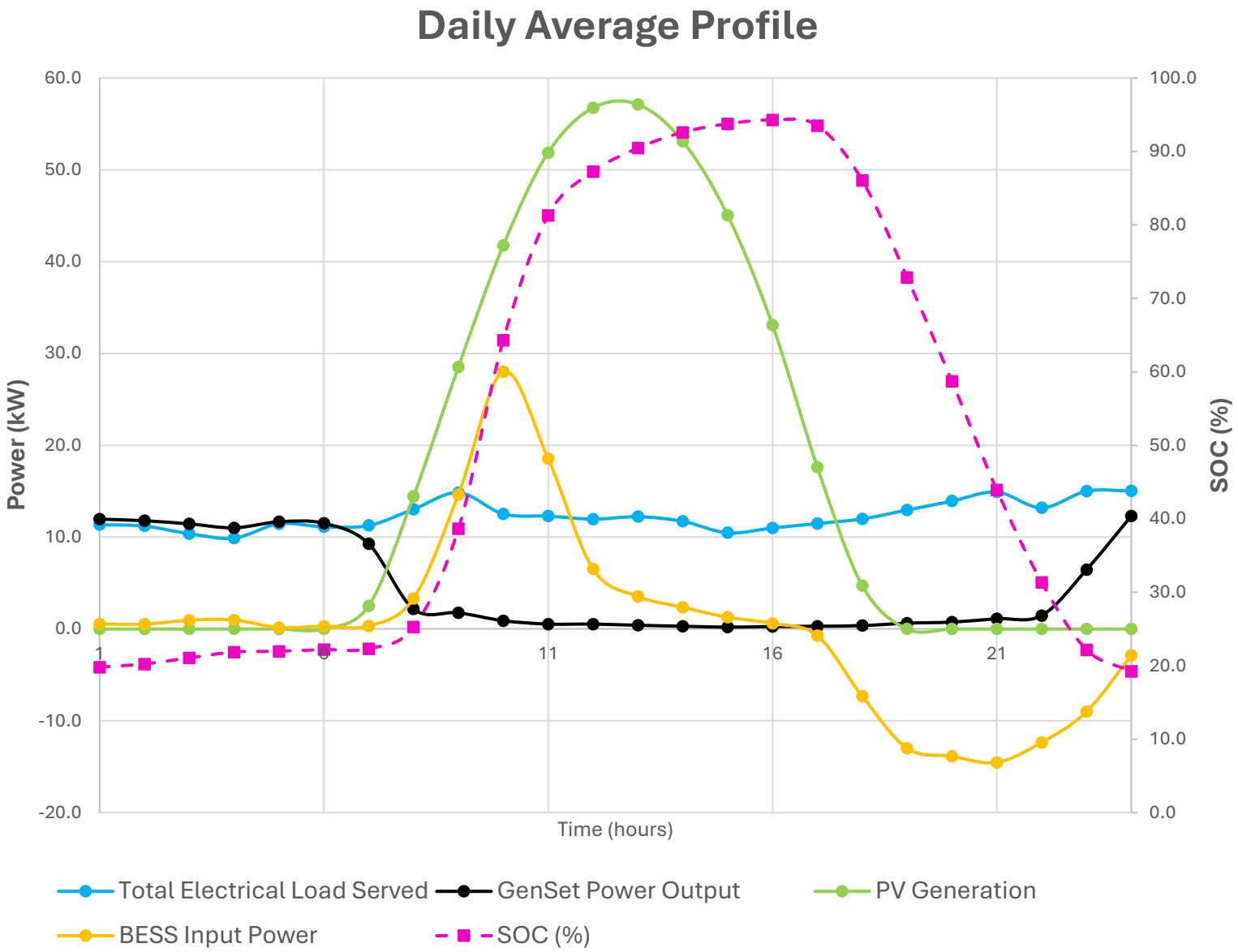
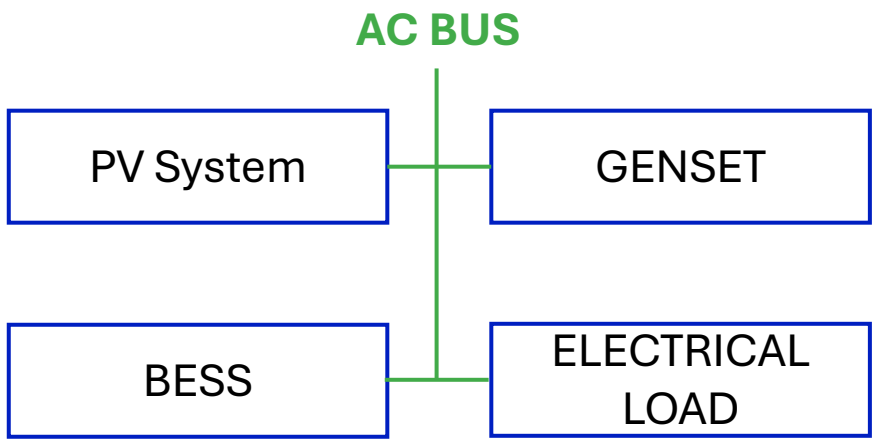
Case Study

Offgrid Application (Genset + PV + Storage)





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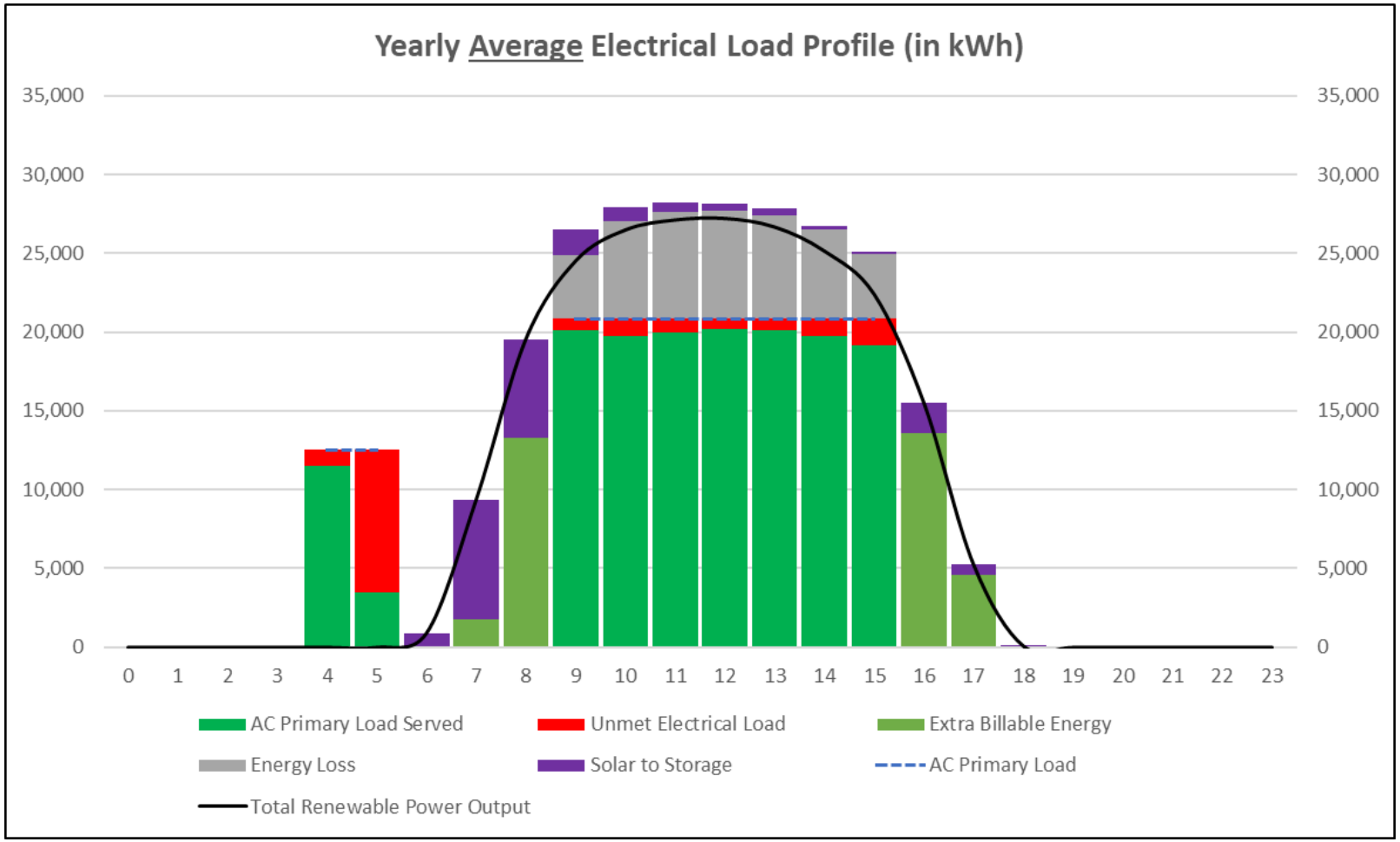
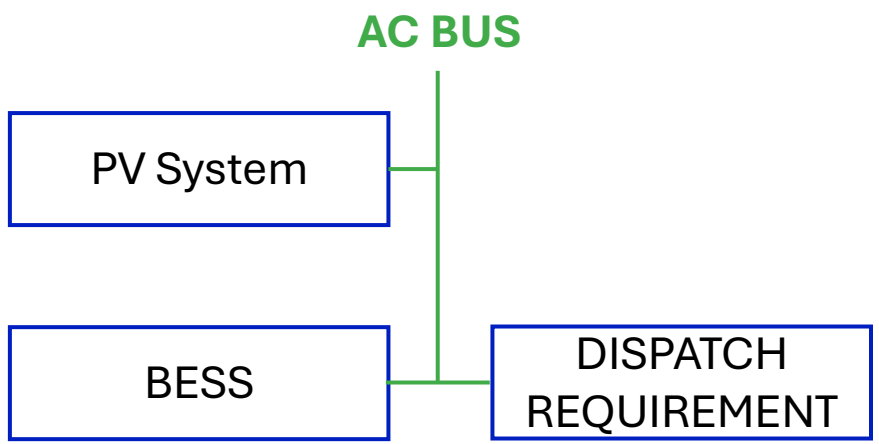
Collocation Application (Grid + PV + Storage)





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Thank you

rizky.pratama@gurinenergy.com

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Lithium-Ion Battery – Sub Chemistry

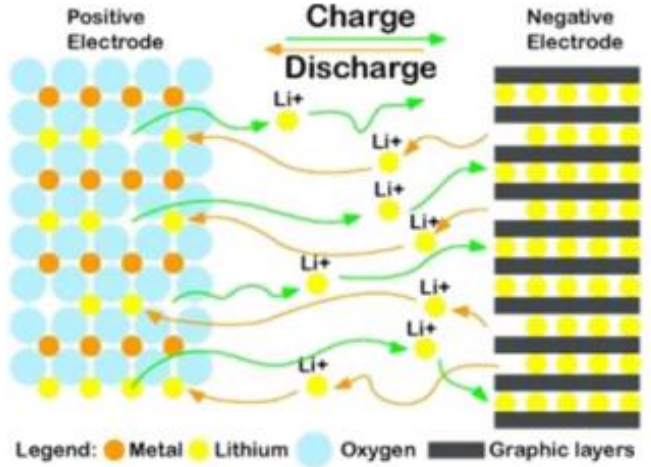
Working principle

While charging, Li-Ions move from the cathode to the anode and are intercalated into the graphite (carbon) layer. During discharge the Li-Ions move via the electrolyte to the cathode structure

Cylindrical

Prismatic

Pouch



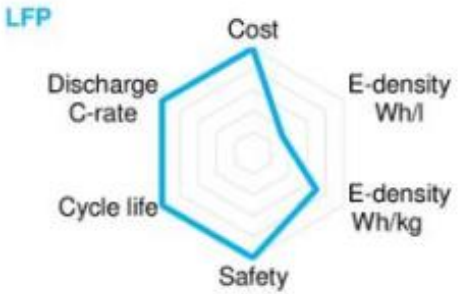
Sub-chemistries

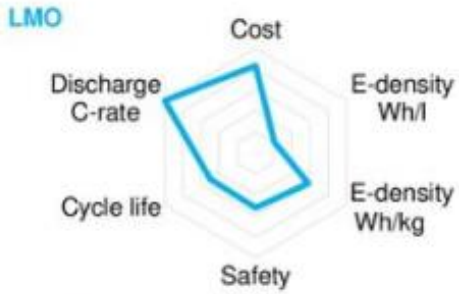
LFP
Lithium Iron Phosphate

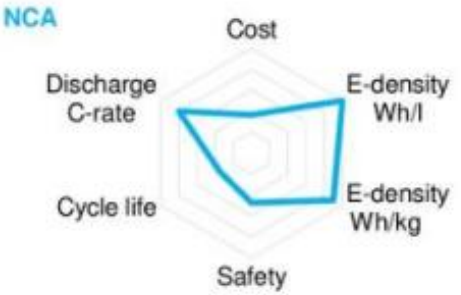
LMO
Lithium Manganese Oxide

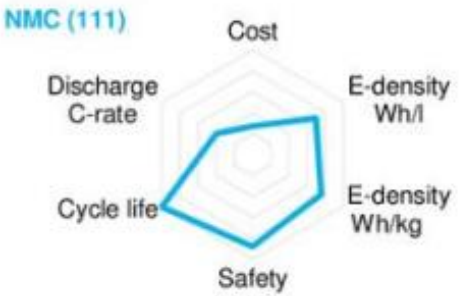
NCA
Lithium Nickel Cobalt Aluminium Oxide

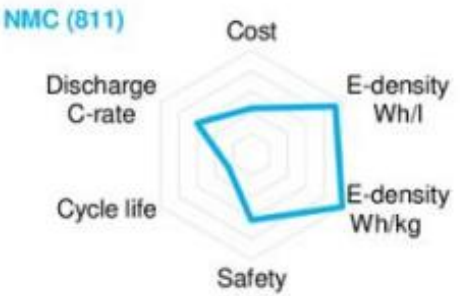
NMC
Lithium Nickel Manganese Cobalt Oxide











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